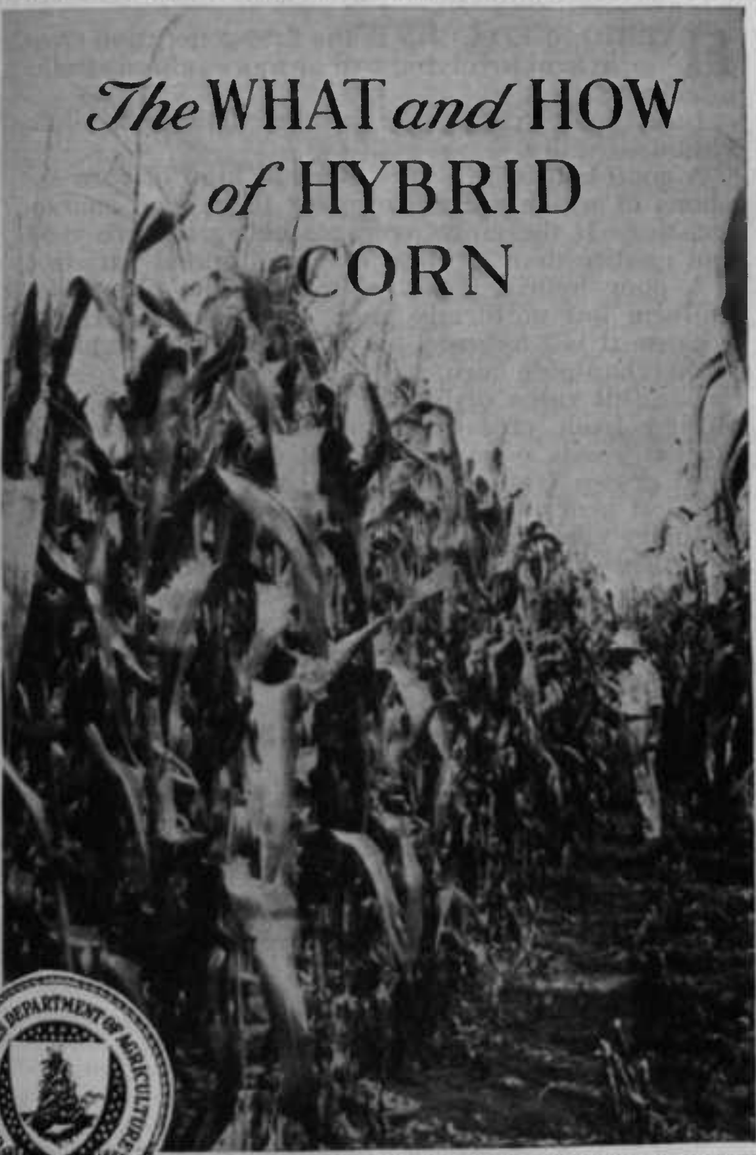
U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1744

The WHAT *and* HOW *of* HYBRID CORN



REPRODUCTION IN CORN

In order to understand just what hybrid corn is, it is necessary to know how the corn plant reproduces. Each kernel of corn results from the fertilization of an egg by a sperm. The egg is at the base of the silk, and the sperm is in the pollen. It is therefore customary to speak of the plant on which the ear is produced as the female parent and of the plant or plants supplying the pollen as the male or pollen parents.

Ordinarily, corn is wind-pollinated, the pollen being carried at random through the air and some of it falling on receptive silks. There it germinates, sending down a pollen tube through which the sperm reaches the egg to effect fertilization. Selecting an ear from a good plant, accordingly, is selecting a good female parent only. Each kernel on the ear may have been pollinated from a different male parent plant. It is this condition that has made it impossible to select varieties of corn that breed true for any but the most simple characters. The breeder sees only what the female parent is like; the pollen parent is unknown. Moreover, many characters are not expressed in the hybrid condition. Thus, the ears of a true-breeding white corn that have been pollinated by a red corn are white, but if such cross-pollinated white seed is planted, all the ears will be red. Then, if this red corn is planted, about one-fourth of the resulting ears will be white and three-fourths red.

In spite of these difficulties, the better varieties of corn have been developed to a relatively high state of productiveness by careful selection over a long period. That is, by selecting seed only from the most productive plants each year, the unfavorable characters have been reduced to such a small proportion that any one is expressed but seldom. Always, however, even in the best varieties, most of the plants are below par because of one or more unfavorable characters, and some of the plants are barren or produce only nubbins because of serious inherited faults.

SELECTING INBRED STRAINS

The development of a good hybrid comprises (1) obtaining the best possible inbred lines or strains and (2) finding those that can be crossed into the best hybrid combination of one kind or another for commercial utilization. The final hybrid is thus the product of many years' careful selection and experimentation. During this breeding period all pollinations are made by hand. Ear shoots are protected from stray pollen by being covered with small paper bags until after the silks emerge. Pollen from tassels that also have been protected then is applied to make the desired mating (fig. 1), and the pollinated ear shoot is again protected (fig. 2). In this way the parentage on both sides is definitely controlled.

In selecting inbred strains, good plants of one or more varieties of corn are self-pollinated, that is, pollen is placed on the silks of the same plant from which it came. The best of the resulting ears are planted, an ear to a row, and good plants within these rows again are self-pollinated, and so on for several generations. Each year, however, only the ears from the best plants from the best rows are selected for continuing the various strains.

With a continuation of this inbreeding there is a marked increase in the uniformity of the plants within any progeny row, although the differences from row to row are extreme. Some strains are dis-

FIGURE 1.—Applying pollen from a selected plant to an ear shoot that was previously protected from stray pollen and will again be protected. (See fig. 2.)

carded almost at once because of grossly unfavorable characters. Others are better and are continued. After some 5 to 7 generations of self-pollination the strains breed practically true for whatever char-

acters they possess. Every plant of any strain is practically like every other plant. After this it is unnecessary to self-pollinate in propagating a strain. Pollination between plants of a strain is then essentially like self-pollination.

So far, among the thousands of inbred strains that have been isolated in this way, none has been found which even approaches ordinary corn in size or production. Nevertheless, no two strains have exactly the same set of faults, and some of them have characters of outstanding value. Thus, some regularly produce long ears, others have stiff stalks or good roots or are resistant to heat, or cold, or disease and the like. It is the problem of the corn breeder to bring these good characters together in desirable combinations. It already has been noted that white corn crossed with red and planted will produce only red corn in what is known as the first hybrid generation; but white will recur in the following or second generation. Many characters are not expressed in the hybrid condition, and this is particularly true of characters unfavorable to growth and production. Consequently, when two inbred strains are crossed or hybridized, the better characters of both parents tend to be expressed in the first generation, just as the mule more nearly approaches the size of the horse and the stamina of the ass.

FIGURE 2.—Method of covering corn-ear shoots with paper bags after pollination from a selected plant, which insures against partial pollination by an unknown male parent.

Because the inbred strains breed true, they provide the corn breeder with fixed material with which to work, the first he has ever had. The faults and virtues of the strains and of their hybrid combinations can be determined by actual test in successive years and under different conditions, with the knowledge that once hybrids are found that are good under several sets of conditions, they can be reproduced with certainty from year to year indefinitely.

FINDING GOOD HYBRID COMBINATIONS

To a certain extent the corn breeder can select inbred strains for crossing on the basis of his knowledge of their characters. Thus, strains with weak stalks, poor root systems or short ears in general must be crossed with strains having sturdy stalks, good root systems or long ears to provide a reasonable chance of having a good hybrid.

This will not always work, however, and beyond this he must rely on testing large numbers of hybrids to find those strains that combine best. The inbred strains producing the poorer hybrids are discarded. Those producing the best hybrids are again crossed and the hybrids tested more adequately. Eventually, through continued elimination and selection, a few lines that combine to advantage in several combinations are found. Finally, some 2 or 3 combinations that have been among the best in a given locality during several seasons are placed in commercial production.

DIFFERENT KINDS OF HYBRIDS

Inbred strains may be combined into several different kinds of hybrids. Thus the single cross or hybrid is between 2 inbred strains, the three-way cross involves 3 strains, the double cross 4 strains, and the top cross involves 1 inbred strain and 1 open-pollinated variety. Each of these has certain advantages and disadvantages or fits into the corn-breeding program in a particular way.

The simplest of these hybrids is the single cross, or hybrid between two strains. Thus, designating the female parent first in the customary way, B×A designates the single cross of strain B pollinated by strain A. The seed of the cross is that produced on the plants of strain B and usually will not appear noticeably different from self-pollinated seed of B. The vigor of hybridity becomes evident, however, shortly after germination begins if the crossed seed is planted.

The three-way cross is the hybrid of a single cross between two inbred strains and a third inbred strain. It is customary to use the single cross as the female and the third inbred strain as the male parent in producing a three-way cross. Thus, (B×A)×C designates the single cross B×A pollinated by strain C. The crossed seed produced on the vigorous B×A plants is superior in quality and quantity to that produced on inbred plants as in single crosses.

Double crosses are hybrids between two single crosses, involving four different inbred strains. Thus, the double cross or hybrid (B×A)×(C×D) designates the hybrid of the single cross B×A pollinated by the single cross C×D. Here, both the male and female parent plants are vigorous hybrids. The seed quality and production are high, and there is every possible assurance of abundant pollen from the male parent, which is not true when this parent is an inbred strain.

The cross of a commercial variety and an inbred strain has been variously designated as a top cross, inbred-sire cross, and the like. In limited experiments, some such crosses have yielded more than ordinary varieties but less than comparable double crosses.

The make-up of double-cross hybrid seed is illustrated in figures 3 and 4. The four ears labeled B, A, C, and D (fig. 3) represent the product of the inbred parent lines. If these are self-pollinated they will reproduce ears like those shown year after year. Seed from ear B, however, when pollinated with pollen from the plant producing A, produces the single cross B×A, shown immediately below its parents. Similarly the single cross C×D is produced from seed on ear C that was pollinated by pollen from plants producing D ears. The ears on the B×A plants, cross pollinated by pollen from C×D plants, then provide the first-generation seed of the

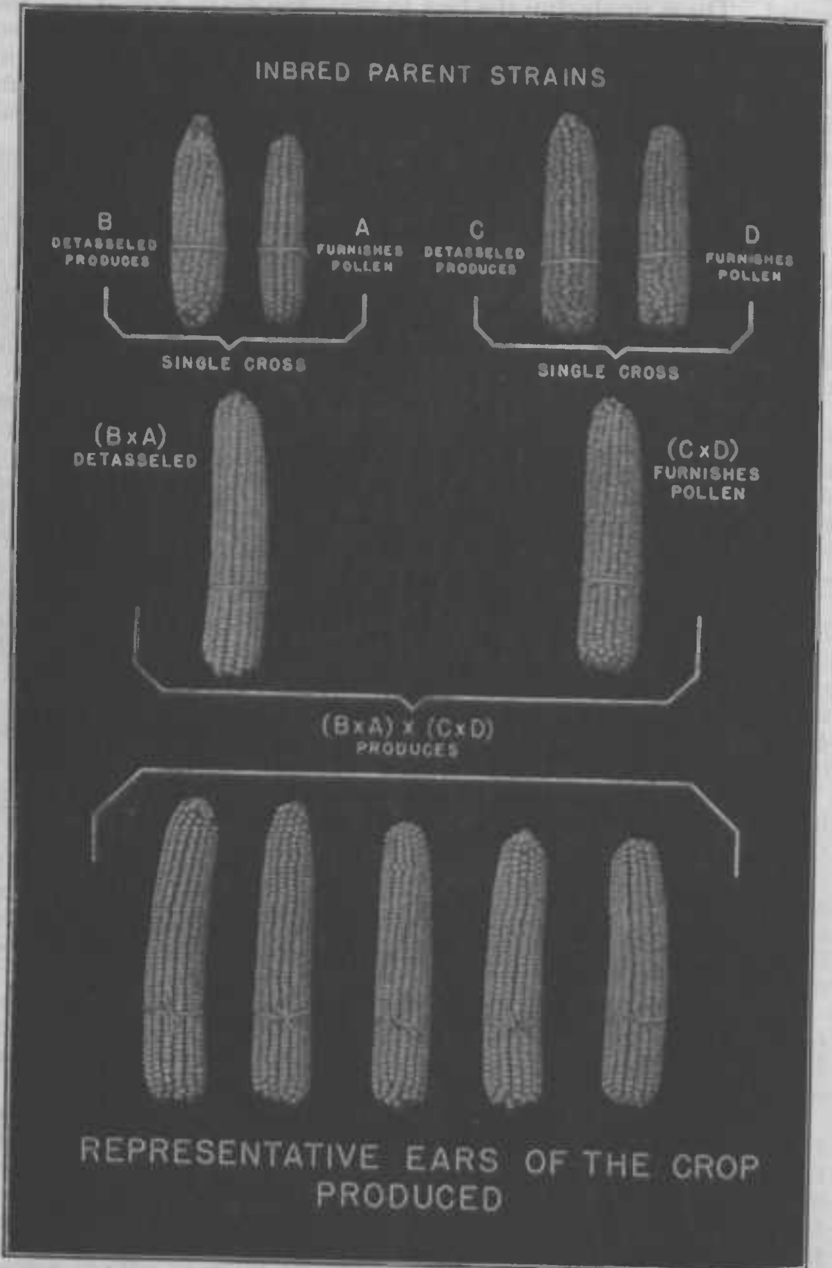


FIGURE 3.—Method of producing double-cross hybrid seed corn and representative ears of the crop produced from hybrid seed.

double cross (B×A)×(C×D), which is used in growing the ordinary corn crop. The ears at the bottom of figure 3 represent what is produced in such commercial fields. The ears produced on the C×D plants grown to furnish pollen are used for feed or commer-

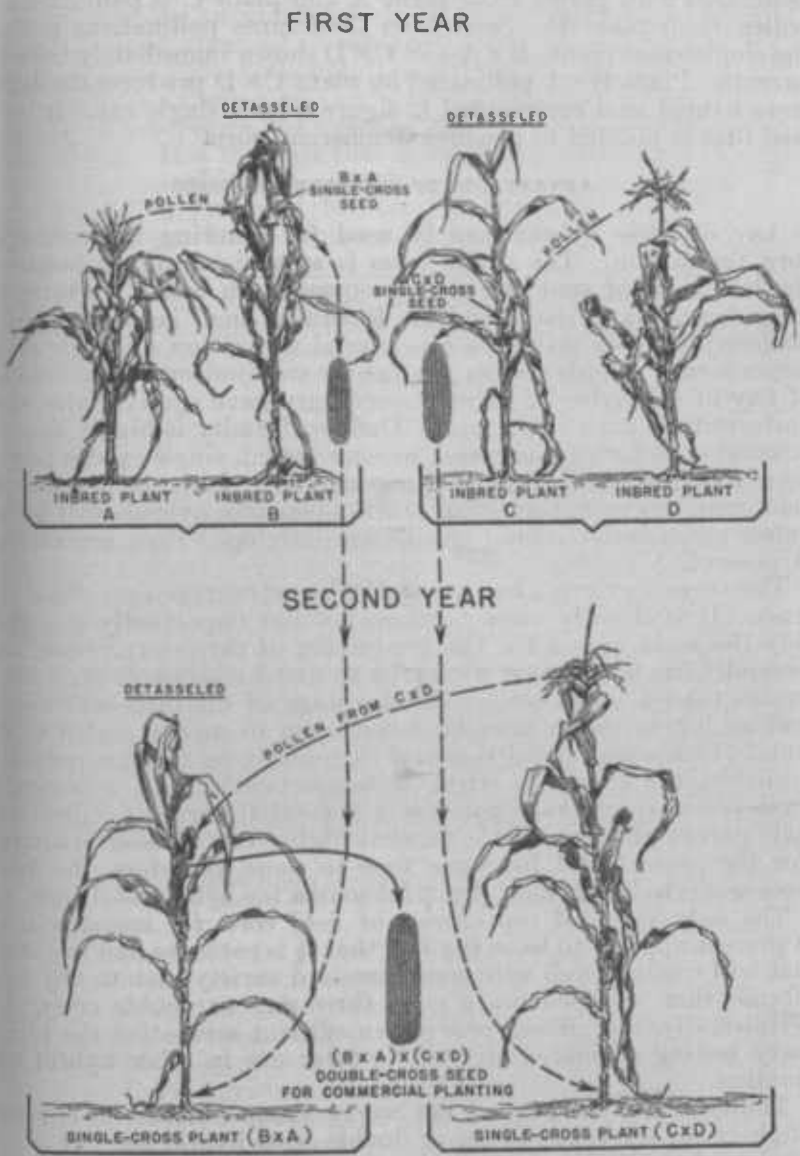


FIGURE 4.—Diagram of method of crossing inbred plants and the resulting single crosses to produce double-cross hybrid seed. A field grown from such hybrid seed is shown on the cover of this bulletin.

cial corn. The seed from these ears may be planted to produce pollen-furnishing plants for another crossing block the next year. Such seed is referred to as advanced-generation seed and is equal to first-generation seed for producing pollen parent plants, but these

will yield on an average only about two-thirds as much grain as the first generation.

The situation is perhaps clearer from figure 4, which shows the system of crossing beginning with the inbred plants. Plant B is pollinated with pollen from plant A and plant C is pollinated with pollen from plant D. Seed from these cross pollinations produces the single-cross plants B×A and C×D shown immediately below the parents. Plant B×A pollinated by plant C×D produces the double-cross hybrid seed represented in figure 4 by a single ear. It is this seed that is planted to produce commercial corn.

ADVANTAGES OF DIFFERENT HYBRIDS

Any of these hybrids can be used for planting for commercial corn production. The single cross is at a disadvantage because of the low yield of seed and its consequent high cost. Moreover, the irregular size and shape and the generally small kernels of present field-corn inbreds make the commercial utilization of single crosses impractical. Single crosses produce the most uniform plants and ears of any of the hybrids. They accordingly have special value where uniformity is most important. Thus uniformity is highly desirable in sweet corn for canning, and, to some extent, single crosses between inbred strains are being used commercially for this purpose. In field corn, however, three-way and double-cross hybrids will be used unless much better inbred strains are developed than are available at present.

The three-way cross has no particular advantage over the double cross. It is slightly more uniform but not importantly so. Probably the main reason for the production of three-way crosses commercially has been that it was easier to find 3 reasonably good inbred strains than 4. The serious disadvantage of the three-way cross is that an inbred strain must be relied upon to supply pollen for the cross. Unless an inbred that can be counted on for this purpose is available, the three-way cross is impractical. Even a reasonably good pollinating strain requires a somewhat larger proportion of male parent plants with a somewhat higher cost of seed production. For the present and for some time to come, therefore, the double cross seems to be the most practical source for hybrid seed corn.

The only value of top crosses of field corn for commercial use at present appears to be in the fact that it is easier to find one inbred that will combine well with some standard variety than to find 3 or 4 inbreds that will produce a good three-way or double cross. Experimentally, top crosses provide an efficient means for the preliminary testing of inbred strains for later use in other hybrid combination.

The user of hybrids need not worry about whether he is getting single-cross, three-way cross, or double-cross hybrid seed, if it is of good quality (quality including size and shape suitable for machine planting) and if it has a definite record of productiveness in his community. The producer of hybrid seed will be governed largely by his individual facilities and the inbred strains that are available to him.

PRODUCING HYBRID SEED CORN

Regardless of what kind of hybrid seed is involved, only the first generation of the hybrid should be sold or used for commercial planting. Only from this generation, i. e., the seed that was actually cross-pollinated by an unrelated strain or hybrid, is the maximum benefit of hybrid vigor to be obtained. The second generation of any double-cross hybrid, that is, the seed produced by the first generation, may be expected to yield from about 10 to 25 percent less than the first generation, the exact decrease depending upon the particular hybrid. It is this fact that necessitates producing the hybrid anew for each season's use.

Hybrid seed is produced for commercial use by growing rows of the two parents in an isolated field and detasseling the plants

FIGURE 5.—An isolated crossing plot at the Iowa Agricultural Experiment Station. The tassels have been pulled from female parent plants growing in four-row blocks, the tassels being left in every fifth row to supply all the pollen in the plot.

of the female parent. In general, a field for this purpose should be not less than 40 rods from other corn unless there are buildings, trees, or other barriers between, or unless the two fields do not tassel at the same time. From 2 to 4 rows of the female parent can be planted to every row of male parent. An isolated crossing block at the Iowa Agricultural Experiment Station, with 4 rows of the female parent (detasseled) to 1 of the male parent, is shown in figure 5. If an inbred strain is to furnish pollen, it is safer to plant not more than 2 rows of the female parent. If a vigorous hybrid is to be the male parent, 4 rows of the female parent can alternate safely with 1 row of the pollen parent in the Corn Belt. As the seed comes only from the female-parent rows, this is a good reason for using a vigorous male parent.

DETASSELING AT BLOSSOMING TIME

During blossoming time the field is gone over at regular intervals, and all tassels are pulled from the female-parent plants before they shed pollen. With few exceptions the tassels emerge enough so that they can be seen before they begin to shed. A quick upward pull at this time takes the tassel out cleanly without damage to the plant. Tassels pulled too early are likely to bring with them part of the top of the plant, with some damage. On the other hand, it is not safe to wait too long lest the tassels begin to shed before they are pulled. Therefore, it is necessary to go over the field practically every day until detasseling is completed.

For large-scale hybrid-seed production at least two of the inbred strains and primary single crosses also are produced in isolated fields. In small-scale production, as for home use, it is probable that stocks of the inbred parents and single crosses can be maintained more easily by hand-pollinating. A 1-acre unit for producing seed of the double cross (B×A) × (C×D) may be taken as an example. With three rows of the female parent B×A to every row of the male parent C×D, one man easily could take care of the necessary detasseling. On the very safe basis of an estimated acre yield of 40 bushels, the three-fourths of the plants detasseled will produce 30 bushels of double-cross seed. With a loss of one-third in culling, this will provide a minimum of 20 bushels, or enough to plant between 120 and 140 acres from a 1-acre detasseled crossing plot.

Presumably there will be specialized production of the parent strains and single crosses. That is, farmers desiring only to produce seed for their own commercial planting or for sale will be able to buy the single-cross seed needed. Others may wish to maintain their own stocks of parent strains and produce their single crosses. On the basis of 1 acre for producing double-cross seed, some 200 or fewer pollinations would be needed. Thus, 20 plants of each of the parent strains would be ample to maintain these stocks. An additional 90 plants of strain B to be cross-pollinated by strain A, and 30 additional plants of strain C to be pollinated by strain D, would supply enough single-cross seed for the acre, with a liberal margin of safety.

YIELDS OF HYBRIDS

It is clear that the labor and expense of hybrid-seed production can be justified only if the hybrids will yield materially more than the best open-pollinated varieties. The Iowa corn-yield test has been conducted for several years by the Iowa Corn and Small Grain Growers' Association in cooperation with the Iowa Agricultural Experiment Station and the United States Department of Agriculture. Upon payment of the required fee, anyone can enter his corn and have it tested in 1 or more of the 12 (reduced to 9 in 1933) districts into which the State is divided. Entries are divided into two classes, open-pollinated and hybrid. These are tested in such a way that the yields are entirely comparable. Because of the open competition, yields from this test afford excellent evidence of the

extent to which hybrids are superior to the better varieties of open-pollinated corn.

In the 92 district tests of the Iowa yield test from 1926 to 1933, inclusive, the average yield of all hybrid entries exceeded that of all open-pollinated entries by 9.3 percent. Many of these hybrids had been tested in only a preliminary way, or not at all, before entry. Beginning in 1933, a separate class for "regular hybrids" was established, comprising hybrids that were in commercial production in the State, in contrast to those that were only in an experimental stage. The number of open-pollinated and of regular-hybrid entries in 1933 and the average acre yield in each of the nine districts, together with the excess yield of the hybrids, is shown in table 1. The average excess yield of the regular hybrids was 7.9 bushels, or 12.5 percent.

TABLE 1.—*Acre yields of open-pollinated and regular hybrid entries in the Iowa corn-yield test in 1933*

District	Entries		Acre yield		
	Open pollinated	Hybrid	Open pollinated	Hybrid	Difference
	Number	*Number*	*Bushels*	*Bushels*	*Bushels*
1	13	6	58	69	11
2	10	6	65	71	6
3	10	6	87	93	6
4	8	5	40	49	9
5	9	6	63	76	13
6	8	5	59	67	8
7	12	4	67	73	6
8	11	4	58	63	5
9	13	5	74	81	7
Average			63.4	71.3	7.9

These results are not unique. Similar differences in favor of hybrids could be shown for practically all of the Corn Belt States and some others. It seems enough here, however, to present these data as typical of the larger acre yields that may be expected from good hybrids in comparison with the better open-pollinated varieties. In general, the excess yield of the hybrid will tend to be less when yields are low. In other cases, however, the superiority of the hybrid may be much more. This is particularly true when the hybrid is resistant to storm damage, smut, or some other condition to which the open-pollinated corn is more susceptible.

With a bushel of seed corn planting 6 to 7 acres in the Corn Belt, it is conservative to estimate an increased production of 40 to 50 bushels from each bushel of hybrid seed. As this larger yield is produced for the same cost except for seed and harvesting, the use of hybrid seed offers farmers a way of materially decreasing the cost of production, when only yield is considered. Even the present-day hybrids have other advantages, and the corn-breeding programs under way definitely promise further advances.

Hybrid corn produces its larger acre yield to a considerable extent because all of the plants do their part. There are very few barren plants in a field of hybrid corn, and a much smaller percentage of

nubbins. This not only increases the yield but also the ease of harvesting. Cost of husking hybrid corn is still further reduced by its ability to stand up better. Some of the earlier hybrids did not have this advantage, but most of the more recently developed hybrids are markedly resistant to lodging. Hybrids also bear their ears at a much more uniform height than open-pollinated corn, further adding to the ease of harvesting. All in all, it seems likely that the increased ease of harvesting all the crop will compensate for the cost of harvesting the extra yield, leaving the larger cost of the seed as the sole charge against the larger yield.

It is undesirable at this time to overemphasize other possible advantages of hybrids. Their production is relatively new, and time has not permitted bringing many desirable characters together into a single hybrid. Progress already made, however, points to the certainty of breeding strains from which can be produced hybrids having resistance to smut, stalk and ear rots, cold, drought, and other vicissitudes. An example in this class is the Golden Cross Bantam, a single-cross hybrid, developed by the Indiana Agricultural Experiment Station in cooperation with the Bureau of Plant Industry. In 1933 this hybrid sweet corn produced a good crop in many localities in which fields of ordinary varieties produced nothing because of bacterial wilt.

NOT ALL HYBRIDS ARE PRODUCTIVE

It cannot be emphasized too strongly that not all hybrids are productive. The foregoing comparisons are based on the better hybrids. If one can know he is getting a better hybrid, that is all that is of interest. This fact must be known from definite knowledge of the previous performance or from the reliability of the source from which hybrid seed is obtained. The lowest yield in each of the six districts in the southern half of the Iowa yield test in 1931 was made by a hybrid entry. A grower buying hybrid seed just because it is hybrid has no assurance that he will get larger yields, and he may have to pay a tremendous penalty for growing it in getting a low yield or soft, unmerchantable corn.

It should also be emphasized that adaptation is just as important in hybrid seed corn as in ordinary varieties. Hybrids adapted to southern Iowa are too late maturing to be grown safely in northern Iowa. The fact that a hybrid is productive in Ohio is little evidence of its value in Missouri or Kansas.

Finally, hybrid seed corn will not produce large yields in spite of poor soil and poor culture. The plants are more efficient in general. But where fertility or moisture is available for an acre yield of no more than 20 bushels of corn, this condition is the limiting factor whether the seed is that of a variety or of a hybrid. The purchase of hybrid seed to plant on unproductive soil rarely will be profitable.

Good hybrid seed is simply a very efficient kind of seed corn that produces plants that are uniform for certain desirable characters. These plants average better than the plants of open-pollinated varieties. The plants of a poor hybrid likewise are uniform but uniformly poor. There is no magic in hybrid corn, and it should be used only when the value of the particular hybrid is known.

SOURCES OF HYBRID SEED

The purpose of this bulletin is to give information on what hybrid seed corn is and how it is produced. To advocate the immediate and general use of hybrids would be premature in many localities, inasmuch as hybrid seed or the parent inbreds are available in only a relatively few States at the present time. The United States Department of Agriculture and many of the State experiment stations, however, have corn-breeding programs aimed at the production of hybrid seed corn, and within a very few years such seed should be more widely available. Already several commercial seed companies are offering hybrid seed for sale, and some of the State experiment stations are distributing hybrid seed for trial and single crosses for the production of double-cross seed on the farms. Anyone interested in hybrid seed corn should consult his State agricultural experiment station or agricultural extension service for information on the availability of hybrid seed adapted to his locality.

The development of inbred strains for the production of hybrid seed is a more elaborate project than most farmers are justified in undertaking. Occasional individuals with the necessary time and facilities may be interested in this phase of corn breeding. It is suggested that such individuals obtain United States Department of Agriculture Bulletin 1489, Corn Breeding,[2] which contains a more detailed discussion of the principles and practice of this and other methods of corn breeding.

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[2] This bulletin may be obtained only from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 25 cents a copy

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